Engineering Evaluation of a Molten Salt HTF in a Parabolic Trough Solar Field

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Participants

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Concept and Project Overview
Part I

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Concept & Objectives

Utilize a molten salt as the heat transfer fluid in a parabolic trough solar field to improve system performance and to reduce the LEC

In this study, evaluate the feasibility and cost effectiveness of the proposal and, if justified, to set forth short- and long-term development programs to achieve this objective

Perform Phase I evaluation and, if promising, go into more detail in Phase II. If not, stop.

Scope of Phase I

- Examine all critical issues; postulate solutions or approaches
- Identify problem areas
- Carry out conceptual design analyses on:
  - Major equipment (sf, sg, tes, other htf)
  - Annual performance
  - Investment cost and LEC
- Offer go/no-go recommendation to continue

Potential Advantages

- Can raise solar field output temperature to 450-500°C
  - Rankine cycle efficiency increases to ≥40% range
  - ΔT for storage up to 2.5x greater
- Salt is cheaper and more environmentally benign than present HTF
- Thermal storage cost drops 65% compared to recent Nexant/Flabeg results for VP-1; <$20/kWht
- Solar Two experience with salts is pertinent and valuable (relates to piping, valves, pumps)

Potential Disadvantages

- Freezing point of one candidate salt - HitecXL - in 87-130°C range; others higher
  - Leads to significant O&M challenges
  - Innovative freeze protection concepts required

- More expensive materials required in HTF system

- Selective surface durability and salt selection will determine temperature limits

- Solar field efficiency will drop, though emissivity of 0.075 (from 0.1) would regain performance

Some Key Questions

- What is the practical upper temperature limit?
- Is the O&M with salt feasible in a trough field, particularly freeze protection?
- Do materials, O&M, performance, etc. push the solar system capital cost too high, or in fact will the cost be reduced?
- Can we lower electricity cost with this approach? And add important flexibility with thermal storage?

General System Conditions

Solar field outlet salt temperature:	Nominal	450C
	Maximum	~500C
Solar field inlet salt temperature:	to be determined in Task 3 by a tradeoff analysis of steam generator cost, power block efficiency and solar field flow rate.	
Optical characteristics:	Overall optical efficiency	0.75 – 0.80
Emissivity at 350C –	Cermet A/B	0.10 -- 0.07
Power Block	Capacity, MW	55 gross; 50 net
Annual performance runs:		
	Thermal storage capacity	0h, 3h, 6h
	Insolation	Barstow TMY
Collector type	Generic SEGS type; advanced characteristics	
Operating scenario	Solar only; no hybrid operation	
Solar field availability	1.00 (no breakage)	
Power plant availability	Tentative: 0.96 and 2 weeks scheduled maintenance	

Nitrate Salts Under of Consideration

- Solar Salt
  - 60% $NaNO_3$, 40 % KNO_3
- Hitec
  - 7% $NaNO_3$, 53% KNO_3, 40% $NaNO_2$
- Hitec XL
  - 48% $Ca(NO_3)_2$, 7% $NaNO_3$, 45% KNO_3
- Other nitrate mixtures (e.g., $LiNO_3$)

Costs

Salt	Supplier	Delta T, C	Cost, $/kg	$/kWh
Hitec XL in 59% water (42:15:43 Ca:Na:K Nitrate)	Coastal Chemical	200	1.43 3.49 (w/o H_2O)	18.2
Hitec (7: 53 Na:K: Nitrate, 40 Na Nitrite)	Coastal Chemical	200	0.93	10.7
Solar Salt (60:40: Na:K Nitrate)	Chilean Nitrate or Coastal Chemical	200	0.49	5.8
Calcium Nitrate Mixture dewatered (42:15:43 Ca:Na:K Nitrate)	Mixed	200 **150** 100	1.19 1.19 1.19	15.2 **20.1** 30.0
Therminol VP-1 (Diphenyl biphenyl oxide)	Solutia	3.96	100	57.5

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Part II

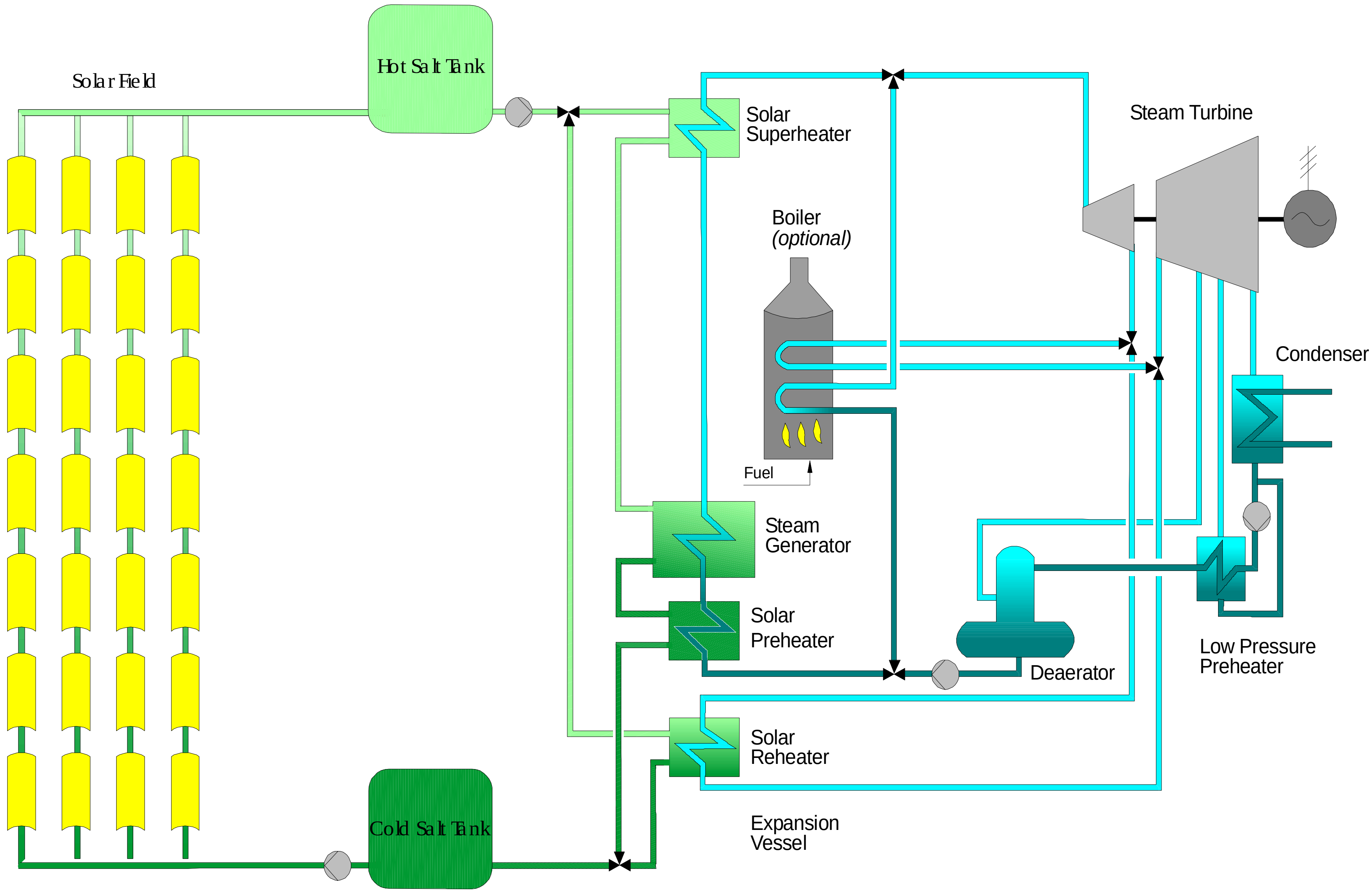
Ulf Herrmann
FLABEG Solar International GmbH

Steps

- Conceptual plant design
- Annual performance calculation
- Estimation of O&M cost
- Estimation of investment cost
- LEC calculation

Plant Design

Plant Design

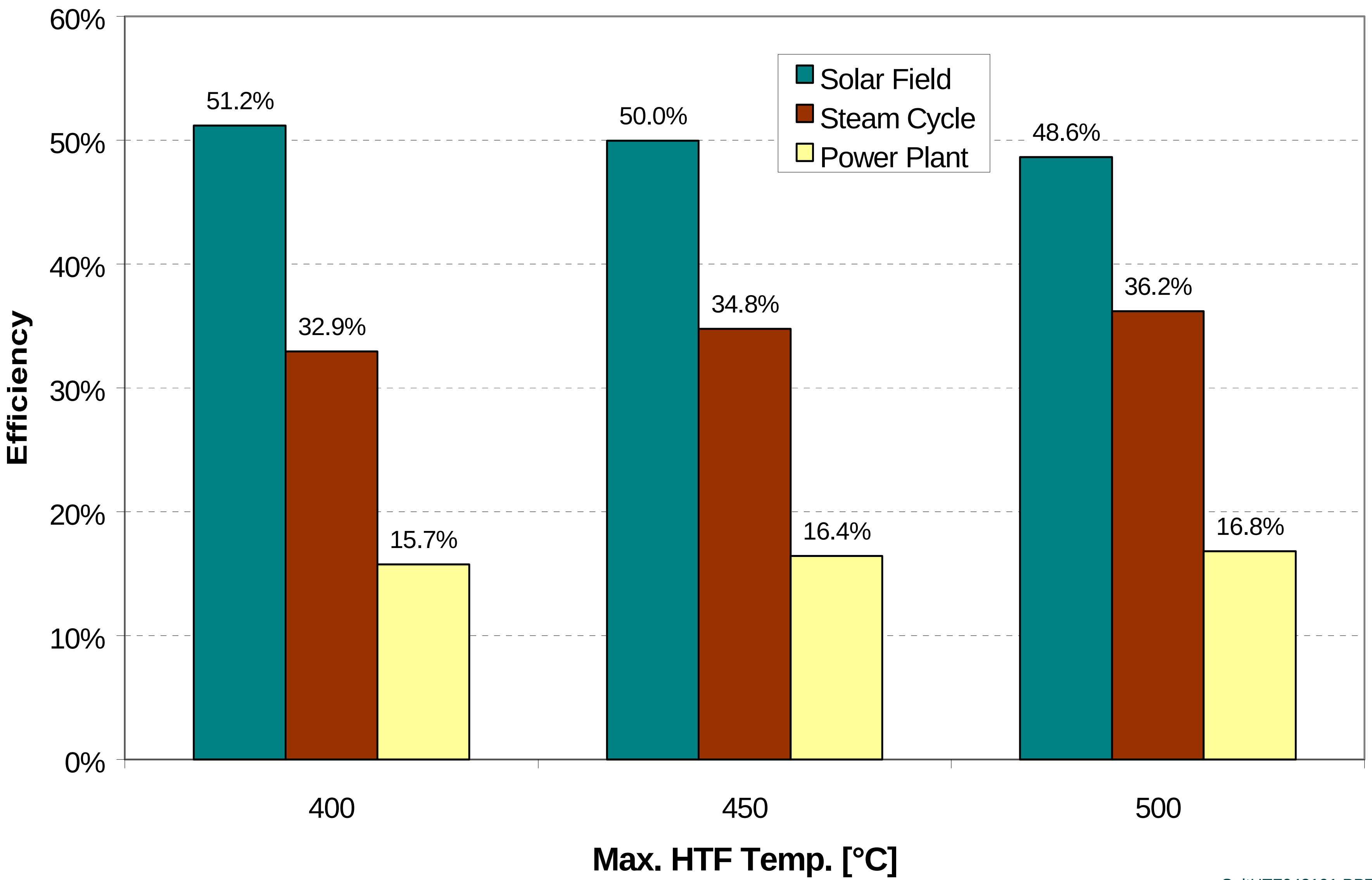


Performance

Impact on Performance

- Improvement of performance because of higher power block operation temperature
- Higher heat losses of solar field because of higher operation temperature
- Due to thermal storage, the number of full load hours increases and number of part load operation hours decreases
- Different heat transfer characteristics and hydraulic behaviour of molten salt flow
- Increased energy needed for freeze protection

Annual Efficiencies



O&M Cost

O&M Cost

- **Plant operation, administration, and power block maintenance costs are unchanged**
- **Solar field maintenance cost increased by 50% for this evaluation**

HTF	VP-1	HITECXL
Plant Size	50 MW / 270000m²	50 MW / 270000m²
Solar Field Maintenance Crew	12	18
Material Cost for Solar Field Maintenance [$/a]	390000	580000

Investment Cost

Investment Cost

- Molten salt is cheaper than VP-1
- Higher operation temperature increases delta T in storage
  → increase of storage capacity and
  reduction of storage cost
- Lower HTF flow in solar field leads to smaller pipes and smaller system volume and lower cost for piping and equipment
- Increase of cost because of freeze protection equipmen

Freeze Protection Devices for Maintenance and Safety

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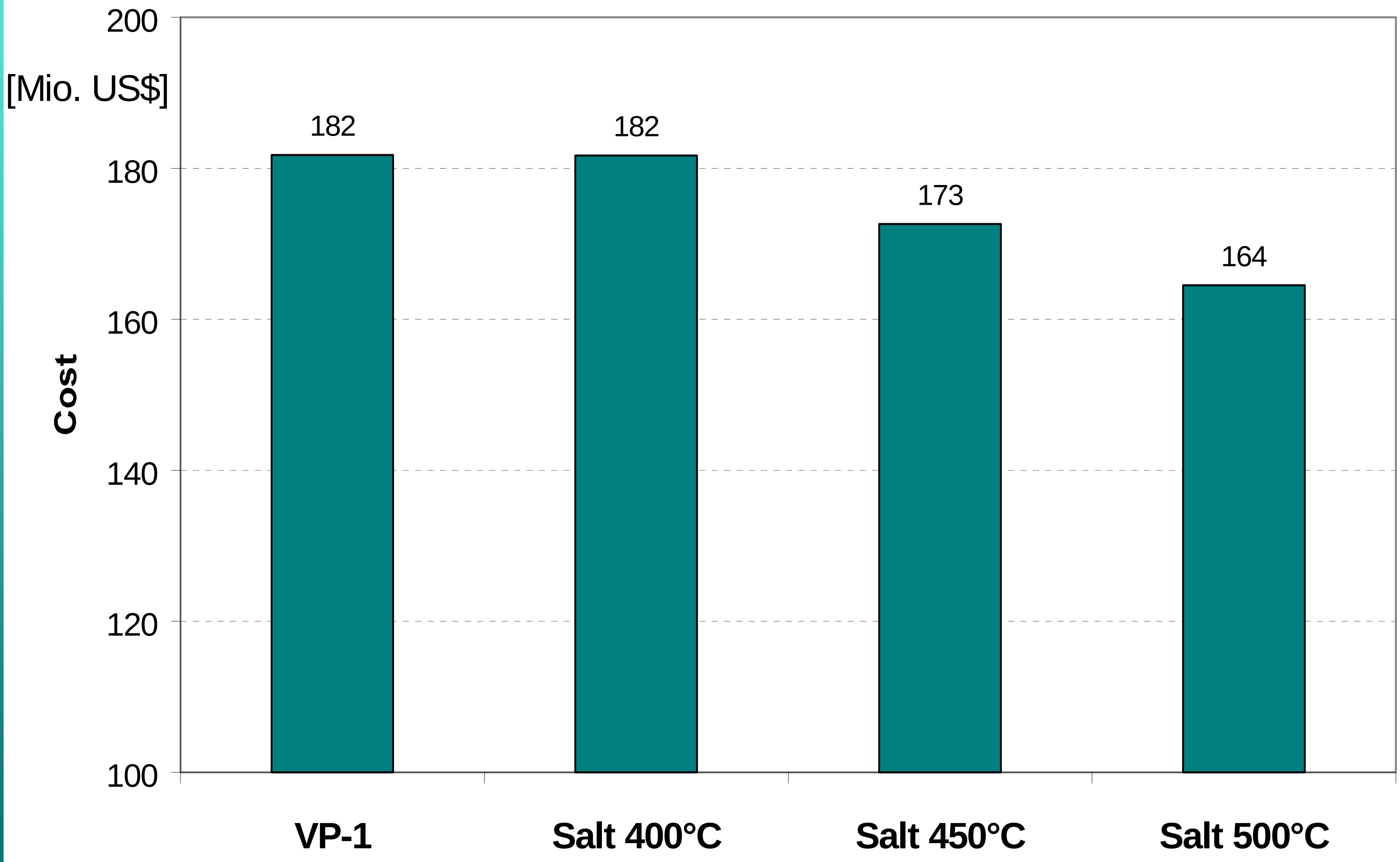
- Heat tracing on all piping and fittings
- Heat trace cable inside the heat collecting element of parabolic trough collector
- Special maintenance truck for draining and filling of loops equipped with heating and cooling devices

Cost for a 50 MW plant with 6h Storage



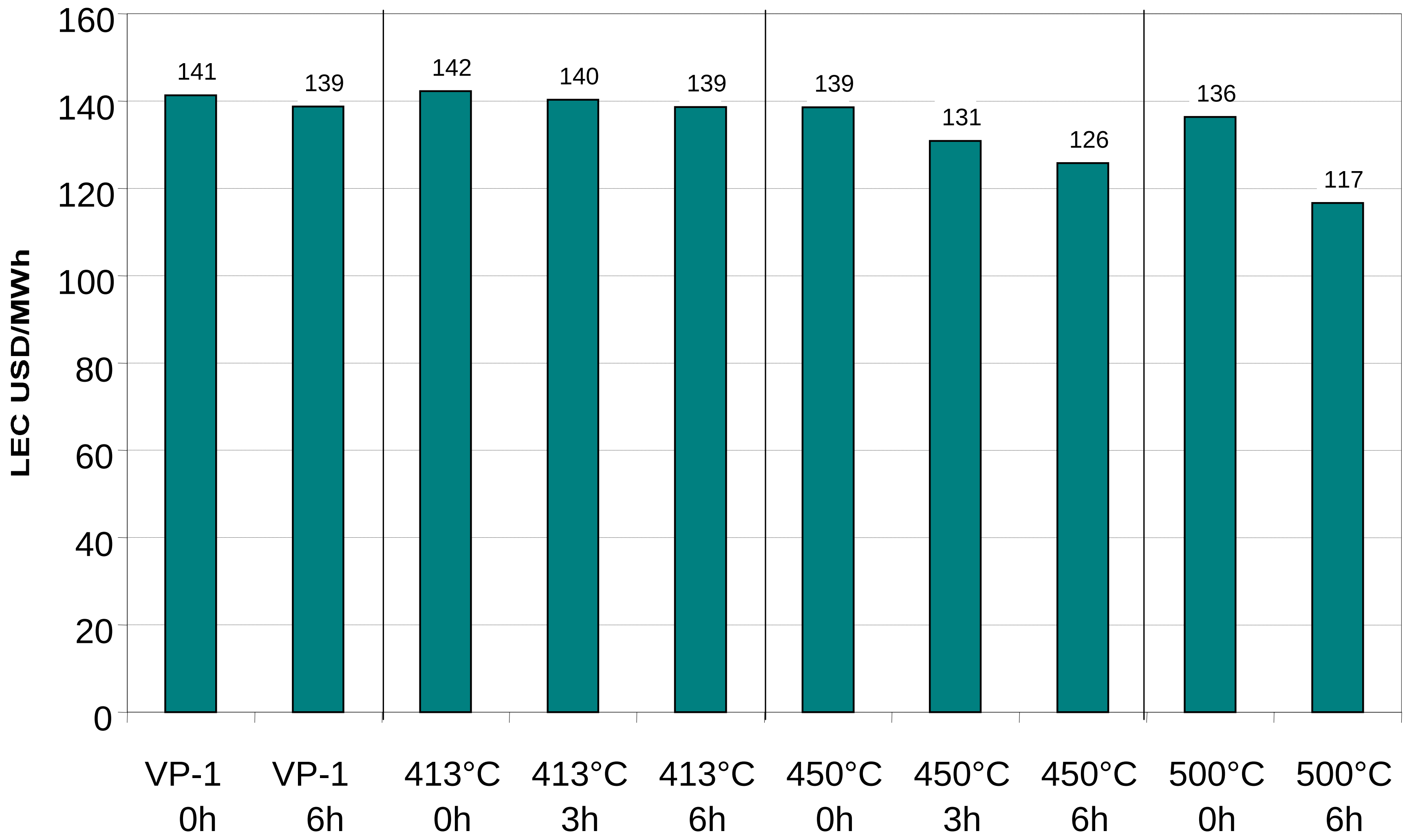
Levelized Energy Cost

Levelized Energy Cost

$$LEC = (\text{Investment Cost x Fixed Charge Rate} + \text{Annual Fuel Cost} + \text{Annual O \& M Cost}) / \text{Annual Net Electricity Output}$$

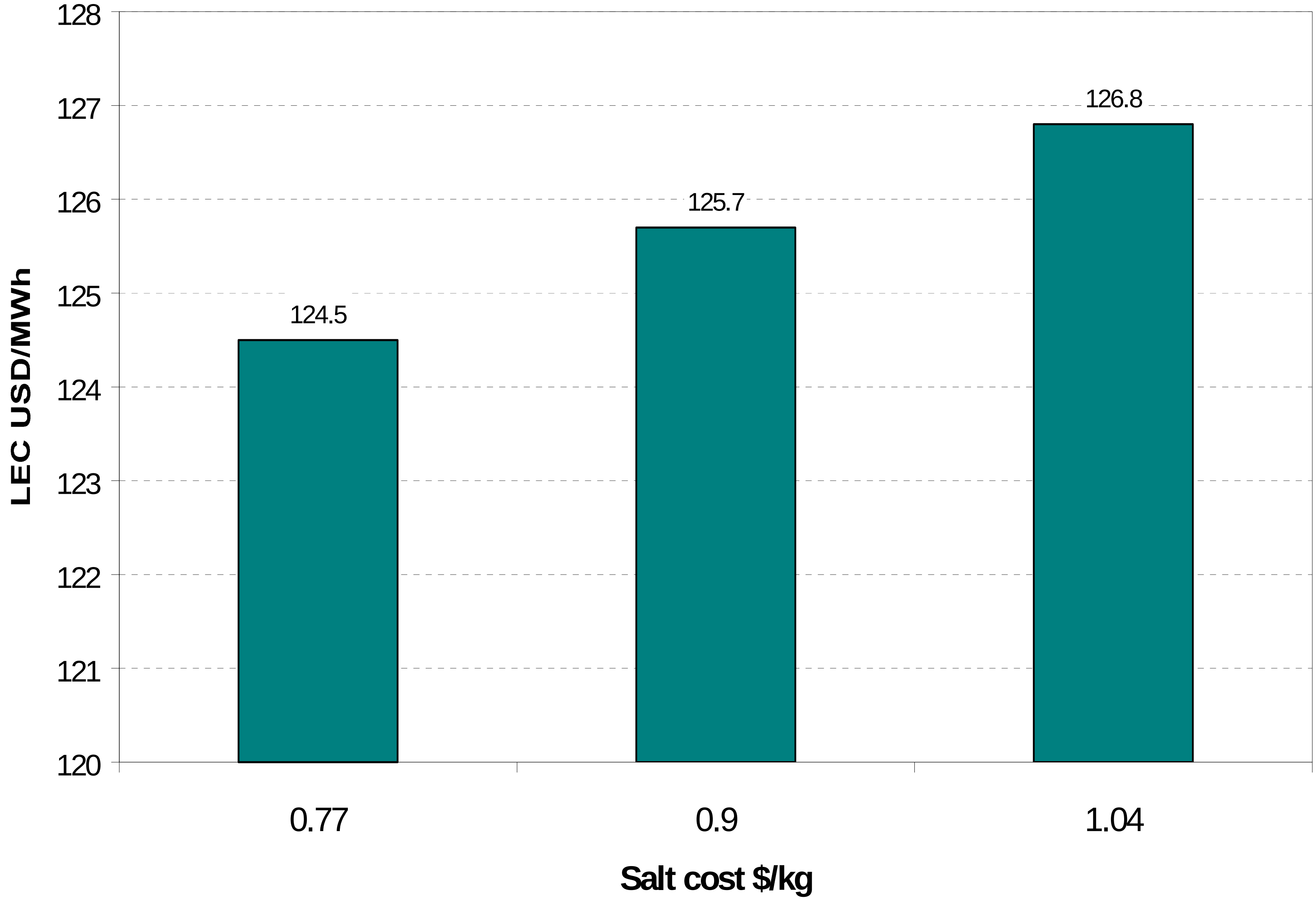
Fixed Charged Rate $\cong$ 0.104

LEC

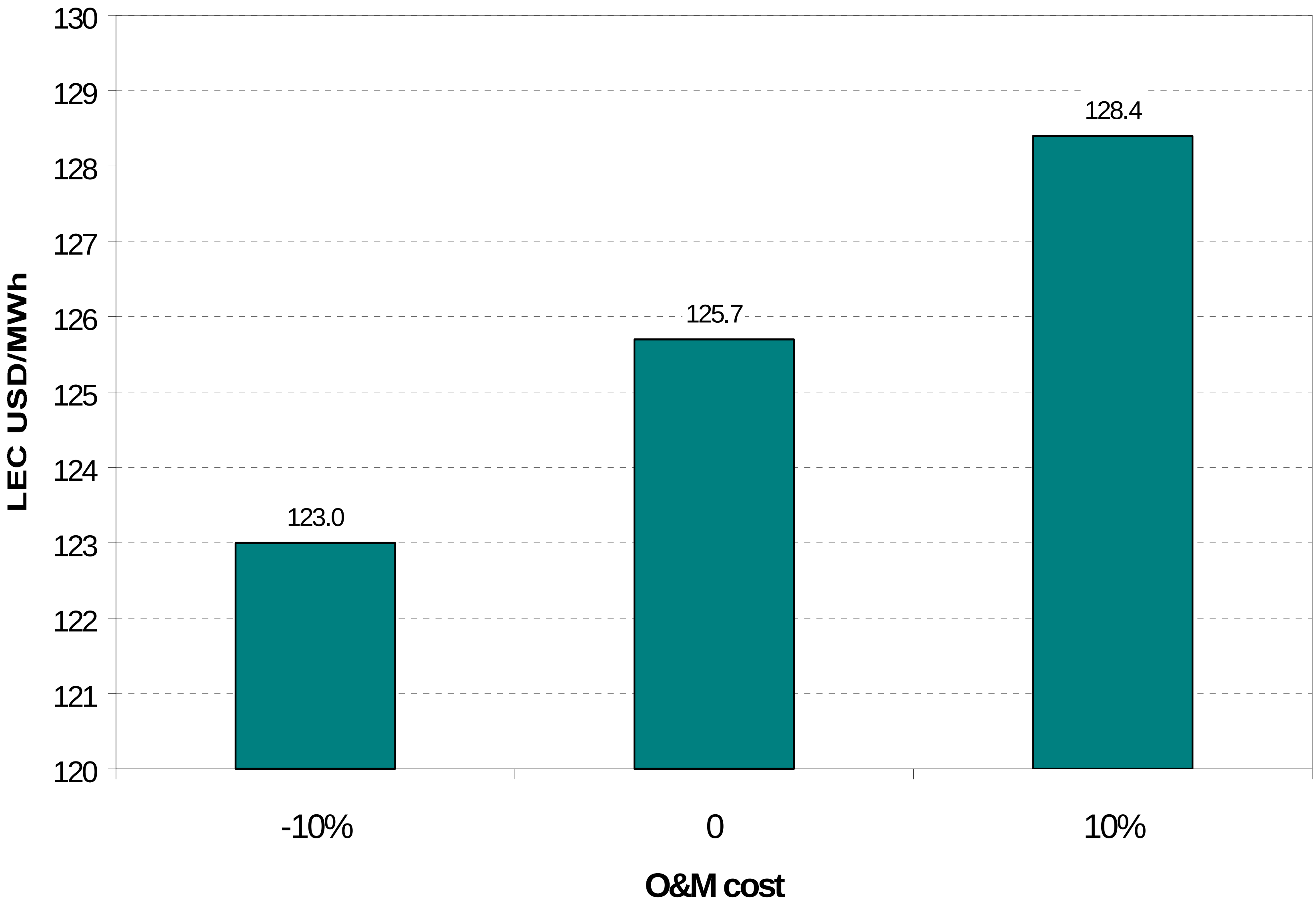


LEC USD/MWh
160
140
120
100
80
60
40
20
0
141
139
142
140
139
139
131
126
136
117
VP-1 0h
VP-1 6h
413°C 0h
413°C 3h
413°C 6h
450°C 0h
450°C 3h
450°C 6h
500°C 0h
500°C 6h

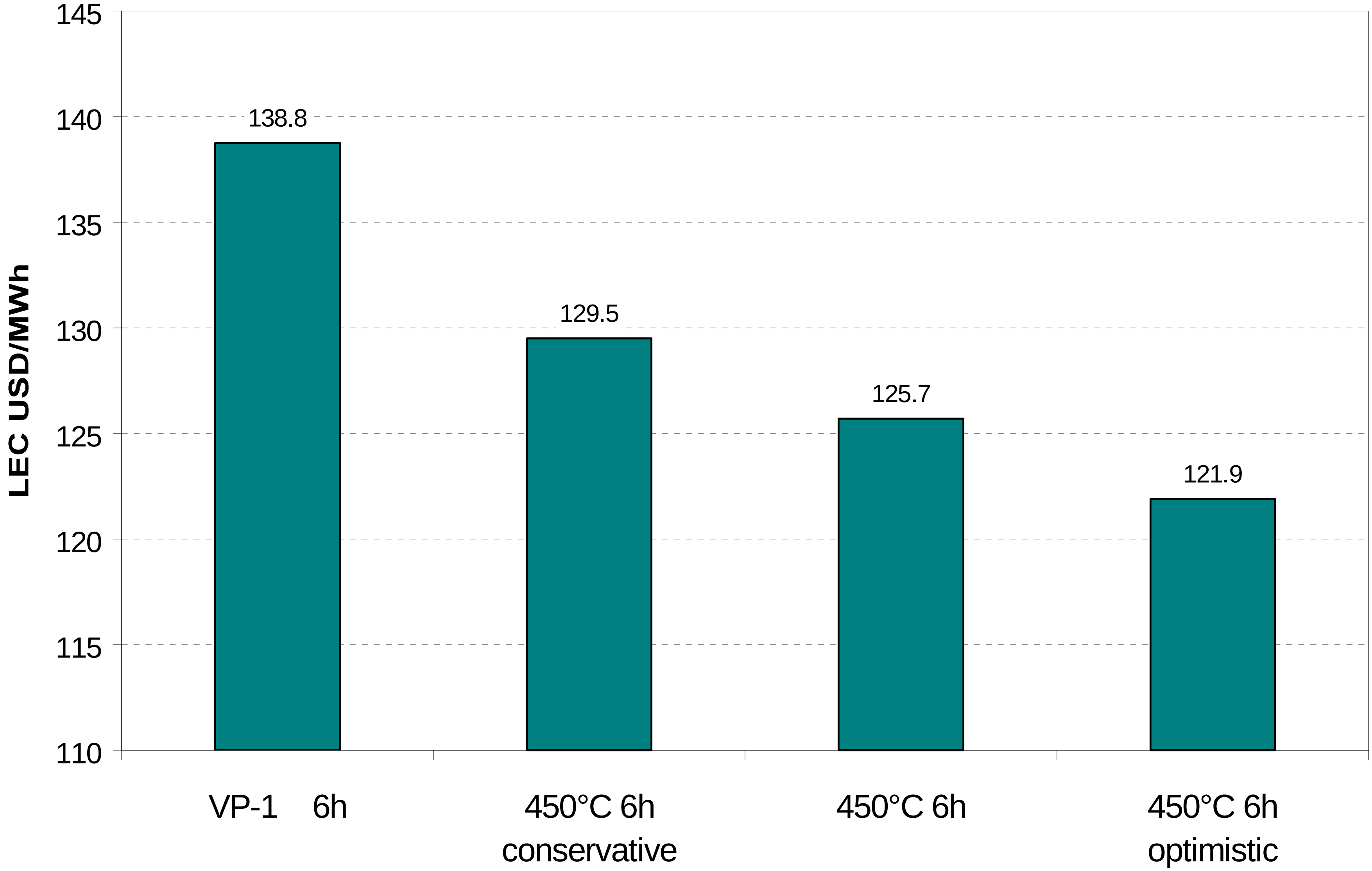
Sensitivity of Salt cost



Sensitivity of O&M cost



Sensitivity of O&M and Salt cost



Conclusions

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- **Salt as HTF does only make sense, if higher operation temperatures than 400°C are feasible**
- **Without storage improvements are only small**
- **Additional energy consumption for freeze protection is 4% of collected solar energy (~1% in the VP-1 reference case)**
- **Improvement of performance is 3 – 7% (freeze protection already included)**
- **Cost reductions of up to 10%**
- **A reduction of LECs of 10 – 15 % compared to current design seems to be possible**
- **Main uncertainties in assumptions (salt cost/O&M cost) do not jeopardize the main conclusion**